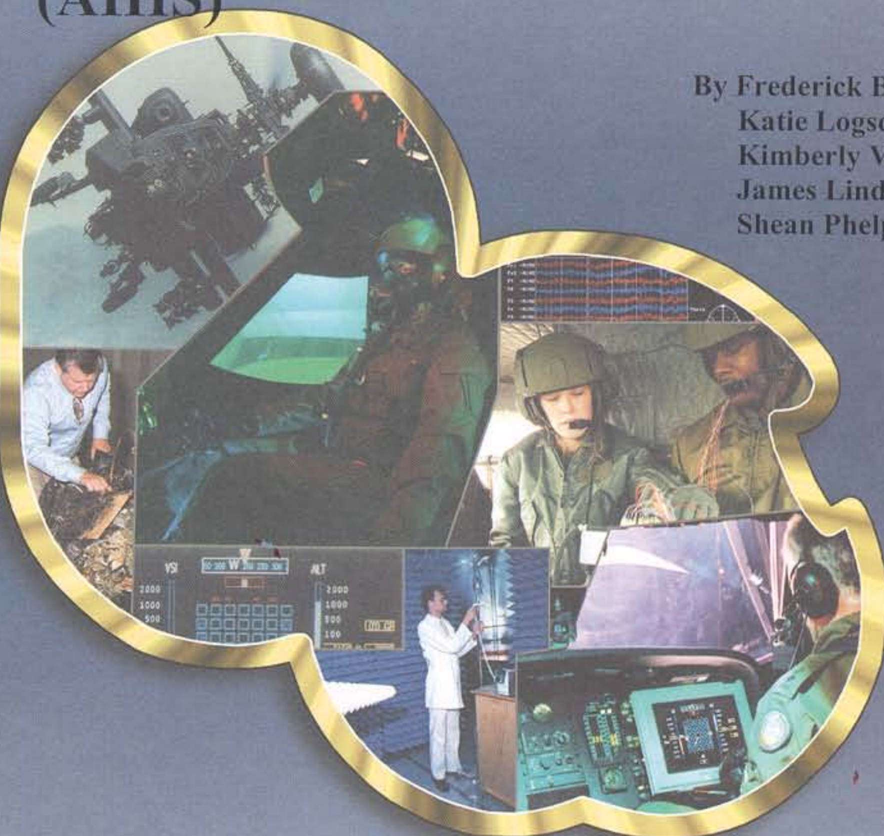
USAARL Report No. 2010-10

Effects of Magnetic Receiver Unit (MRU) Installation on the Blunt Impact Protection of the HGU-56/P Aircrew Integrated Helmet System (AIHS)



By Frederick Brozoski
Katie Logsdon
Kimberly Vasquez
James Lindsey
Shean Phelps

Warfighter Protection Division

December 2009

Approved for public release, distribution unlimited.

USAARL

U.S. Army
Aeromedical Research
Laboratory

Notice

Qualified requesters

Qualified requesters may obtain copies from the Defense Technical Information Center (DTIC), Cameron Station, Alexandria, Virginia 22314. Orders will be expedited if placed through the librarian or other person designated to request documents from DTIC.

Change of address

Organizations receiving reports from the U.S. Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this document when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
11-12-2009	Final	

4. TITLE AND SUBTITLE
Effects of Magnetic Receiver Unit (MRU) Installation on the Blunt Impact Protection of the HGU-56/P Aircrew Integrated Helmet System (AIHS)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Frederick Brozoski
Katie Logsdon
Kimberly Vasquez
James Lindsey
Shean Phelps

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Aeromedical Research Laboratory
P.O. Box 620577
Fort Rucker, Alabama 36362-0577

8. PERFORMING ORGANIZATION REPORT NUMBER
USAARL 2010-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
504 Scott Street
Fort Detrick, Maryland 21702

10. SPONSOR/MONITOR'S ACRONYM(S)
USAMRMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The AH-64 Apache helicopter currently utilizes an electro-optical system for tracking gunner and pilot head motion. A critical component of this system is the Integrated Helmet and Display Sighting System (IHADSS) helmet. As part of the current “Block III” upgrade, Apache Product Management Office has opted to adapt the HGU-56/P Aircrew Integrated Helmet System (AIHS) to accept and utilize a “Magnetic Receiver Unit” to replace the current tracking system. The objectives of this study were to assess overall level of blunt impact head protection as well as parameters of weight and location of the center of mass (CM) of the AIHS when configured with the MRU. Whereas no definitive statement can be made as to the influence of the MRU installation on the blunt impact protection provided by the HGU-56/P when impacted in the rear, this configuration should provide adequate impact protection in survivable rotary-wing mishaps while providing improved impact protection in the rear headband region as compared to the IHADSS. Furthermore, installation of the MRU should not adversely affect the wearer’s ability to identify and track targets.

15. SUBJECT TERMS
AH-64, Apache, Integrated Helmet and Display Sighting System, IHADSS, HGU-56/P, Aircrew Integrated Helmet System, AIHS, Magnetic Receiver Unit, MRU, center of mass, CM, impact protection

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
UNCLAS	UNCLAS	UNCLAS	SAR	40	Loraine Parish St. Onge, PhD.
					19b. TELEPHONE NUMBER *(Include area code)* 334-255-6906

Reset

Acknowledgements

The authors thank the Apache Program Manager's Office for funding this evaluation and Product Manager, Air Warrior for providing the necessary helmet assets. The authors also thank Mr. Steven Carter and Mr. James Cox for his assistance in successfully completing the blunt impact evaluation of these helmets.

Table of contents

List of figures

List of tables

Background

Since initial development and fielding in the 1980's, the AH-64 Apache helicopter has utilized an electro-optical system for tracking gunner and pilot head motion. The aircraft's on-board weapons systems move with these head motions, and as such, the aircraft weapons systems are aimed in the direction of the aviator's gaze. A critical component of this weapons system is the Apache-specific Integrated Helmet and Display Sighting System (IHADSS) helmet (figure 1). Embedded in the outer shell of the IHADSS helmet are electro-optical emitters that are tracked inside the aircraft cockpit by aircraft-mounted sensors. The position of these electro-optical emitters is constantly tracked by the on-board sensors, and used to slew the on-board weapons in the direction that the pilot or gunner is looking.

Figure 1. IHADSS helmet. Arrows point to electro-optical emitters on the right side of the helmet. Two more emitters are mounted in identical positions on the left side of the helmet.

The AH-64 Apache has been continually modernized and upgraded. With the current Block III upgrade to the AH-64, the electro-optical tracking system is being replaced with a magnetic tracking system. Existing electro-optical IHADSS helmets are incompatible with the magnetic-

based system. In lieu of retrofitting existing IHADSS helmets, the Apache Product Manager has opted to adapt the HGU-56/P Aircrew Integrated Helmet System (AIHS) – the primary rotary-wing helmet used by the U.S. Army. To make the HGU-56/P AIHS compatible with the magnetic tracking system, a Magnetic Receiver Unit (MRU) was designed to mount to the exterior surface of the HGU-56/P (figure 2).

Figure 2. Anterior (left) and posterior (right) views of a medium HGU-56/P AIHS configured with an MRU.

Military relevance

Adams et al. (in press) completed a retrospective study of HGU-56/P performance between 1996 and 2004. Seventy (70) helmets from 31 rotary-wing accidents were examined and correlated to the accident and injury reports of the individuals wearing the helmet. For 50 of the 70 helmeted individuals, the accidents were classified as survivable rotary-wing mishaps. Of those 50, more than 50 % (n = 28) sustained no head injury. With the exception of one, the remaining head injuries were limited to mild concussions. The worst head injury sustained during a survivable crash event was a brain contusion. Of the 22 individuals sustaining some type of head injury during a survivable crash, none lost consciousness (Adams et al., in press). This retrospective analysis of HGU-56/P helmets demonstrates the ability of the standard HGU-56/P helmet to protect the wearer from severe head injury.

The primary reason for the success of the HGU-56/P is the stringent blunt impact protection requirements imposed on its design. The HGU-56/P is designed to provide conscious survivability in severe, but survivable rotary-wing mishaps. To achieve this, the helmet is

designed to limit head accelerations to 175 Gs or less when impacted in the headband region at 6.0 meters per second (mps). The Army recognizes 175 Gs as the threshold for consciousness (Slobodnik, 1980). To protect against basilar skull fracture, the HGU-56/P is designed to limit head accelerations to 150 Gs when impacted at 4.0 mps in the crown or at 6.0 mps on the eardomes (Department of Defense [DOD], 1996).

The use of helmet mounted devices increases the head-borne weight and changes the helmet's mass moments of inertia. During crash events, acute neck injury could result from improperly weighted helmets. Extended missions and continuous operations with improperly weighted helmets induce neck fatigue, which can degrade aircrew performance and potentially introduce chronic neck injury.

Any modifications to the standard HGU-56/P helmet may negatively affect the crashworthiness of the helmet. Therefore, any modifications to the standard HGU-56/P helmet are stringently evaluated to ensure the protection provided to the aviation Warfighter is not compromised.

Objectives

The primary objective of this study was to assess the blunt impact head protection provided by the HGU-56/P flight helmet when configured with the MRU. A secondary objective was to determine the effects of MRU installation on the weight and location of the center of mass (CM) of the HGU-56/P.

Materials and methods

Experimental equipment

Helmets

Eight (8) standard HGU-56/P flight helmets and two (2) AH-64 Apache-specific spherical visor assemblies (SVAs) were provided by Program Manager – Air Warrior (PM-AW) for the blunt impact evaluation. Two helmets in each of four sizes (small, medium, large, and extra-large) were received. These helmets were configured with Dual Lock VELCRO® (3M, St. Paul, MN) on the crown (figure 3) prior to arrival at USAARL. An MRU (figure 2) was attached to each helmet by a representative of Elbit Systems of America (Fort Worth, TX) on the day of testing. Additionally, standard dual-visor assemblies (DVAs) (figure 2, left) were removed and replaced with SVAs (figure 4) on one medium and one large helmet.

Figure 3. Mounting location of Dual Lock VELCRO® on the crown of an HGU-56/P AIHS.

One medium and one large HGU-56/P AIHS were used for mass properties measurements. Each helmet was configured with an MRU. Helmets were initially configured with DVAs. Once the initial series of mass properties measurements were completed, both helmets were reconfigured with SVAs.

Figure 4. HGU-56/P AIHSs configured with a DVA (left) and an SVA (right) and MRUs.

Monorail drop tower

Blunt impact attenuation tests were performed on a guided, free fall drop tower (figure 5) conforming to Federal Motor Vehicle Safety Standard number 218 (FMVSS 218) (Department of Transportation [DOT], 2006). Four magnesium headforms were available for these tests; these include the standard small (DOT size B), standard and modified medium (DOT size C), and modified large (DOT size D) headforms (figure 6). The modified headforms have flanges along the left and right sides, allowing greater contact area between the helmet's earcup and the headform. The standard medium headform was used for impacts to the crown and headband (front, rear, left, and right) of small, medium, and large HGU-56/P AIHSs; the modified large headform was used to impact these same sites on the extra-large helmets. The modified medium headform was used for impacts to the left and right eardomes of small and medium helmets. The test headform weights, as defined by the HGU-56/P product description (FNS/PD 96-18) (DOD, 1996), are provided in table 1.

Figure 5. Guided, free fall drop tower (shown with the standard medium headform installed).

Figure 6. Drop tower headforms. Shown from left to right are the standard small (DOT size B), standard medium (DOT size C), modified large (DOT size D), and modified medium (DOT size C) headforms. The modified headforms are configured with flanges along the left and right sides, allowing for more contact between the headform and the helmet earcups and making the headform useful for lateral earcup impact tests.

Table 1.
Test headform drop assembly weight.

Headform size	Required weight (lbs)	Weight tolerance (lbs)***	Actual weight (lbs)
Small (size B)	10.1*		9.9
Medium (size C)	11.0**		11.2
Medium (size C) (modified)	11.0**	+0.2, -0.0	11.1
Large (size D) (modified)	13.4**		13.5

* Per FNS/PD 96-18 (DOD, 1996)
** FMVSS 218 (DOT, 2006)
*** Per ANSI Z90.1-1971 (American National Standards Institute [ANSI], 1971)

Three channels of data were collected during blunt impact tests. A single-axis, linear accelerometer (Endevco model 7264B-500T) installed in the center of mass of the headform measured vertical deceleration of the headform at impact. Impact force was measured using a three-axis impact load cell (Denton model 4773S1) installed beneath the impact anvil. The velocity sensor (GHI Systems model VS300 Velocimeter) output voltage, which triggered the data acquisition system, was also recorded. Data were recorded at 20,000 samples per second per channel.

Mass properties instrument

Mass properties measurements, CM and mass moments of inertia (MOI), were made using a KSR330-60 mass properties instrument (MPI) manufactured by Space Electronics, Inc. (figure 7). CM was calculated using a summation of moments about the test platform's pivot axis. The pivot axis serves as the fulcrum for the test platform, which is suspended by a rotary gas bearing. The force required to balance a test part on the test platform's pivot axis was measured using a force transducer located a known distance from the pivot axis. The distance between the part's CM and the pivot axis was calculated using the measured force, the known distance between the force transducer and platform pivot axis, and the mass of the part (measured using a simple scale prior to testing). MOI was calculated based on the period of rotational oscillation of the test platform, which is configured as an inverted rotary pendulum (Deavers & McEntire, 1996). MPI operation and data collection were automated using a Microsoft™ Windows 98 workstation.

Figure 7. KSR330-60 Mass properties instrument.

A U.S. Army Aeromedical Research Lab (USAARL) mid-size (50^{th} percentile) male headform was mounted to the MPI test platform. The headform could be oriented along three

orthogonal planes: XY, XZ, and YZ. The origin and axis for these headform orientations were coincident with the head anatomical coordinate system (figure 8). The orientations were named based on the axes along which the CM positions were being measured. For example, the headform in figure 7 is oriented in the XY orientation. In this orientation, the anterior-posterior (X) and lateral (Y) CM positions of the helmet are measured. In each orientation, the vertical centerline of the test platform intersected the headform at the tragion notch – the center of mass of the mid-size male head and neck combination. Thus, all CM measurements made using the USAARL headform were relative to the mid-size male head and neck center of mass.

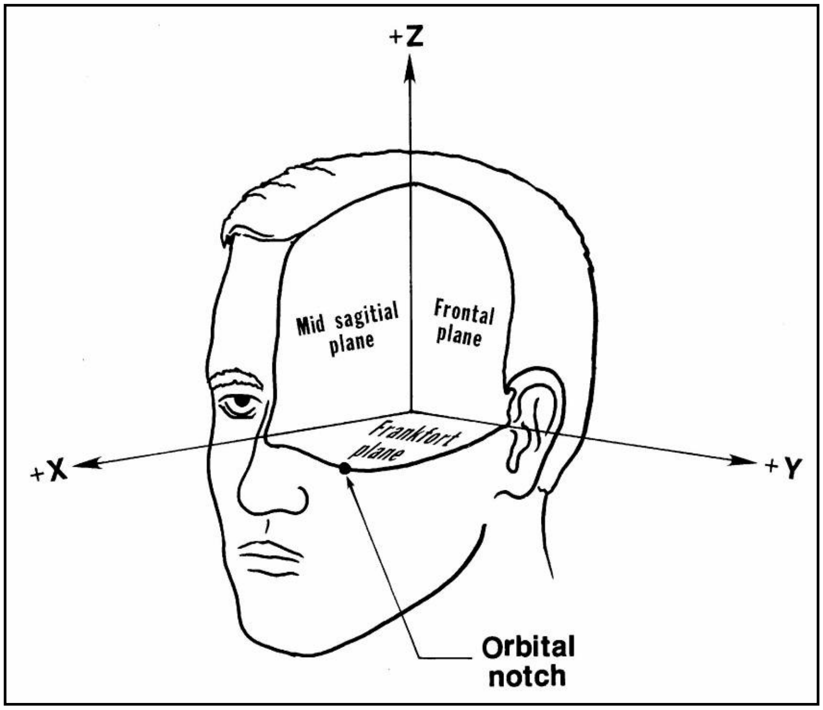


Figure 8. The head anatomical coordinate system.

Experimental methods

Blunt impact protection

Impact zones were marked on one of each size HGU-56/P being tested. Lines marking the boundaries of the crown and headband impact regions were scribed onto the surface of each helmet in accordance with the HGU-56/P AIHS production specification FNS/PD 96-18 (DOD, 1996) (figure 9). After the impact zones were defined, MRUs were attached to each helmet by Elbit Systems of America (ESA) personnel. The helmets were examined to determine the impact zones in which the boundaries of the MRU fell within, as this would dictate the impact velocity and pass-fail criteria used during the evaluation. For each size of HGU-56/P being evaluated, the boundaries of the MRU remained within the crown impact region (figure 10).

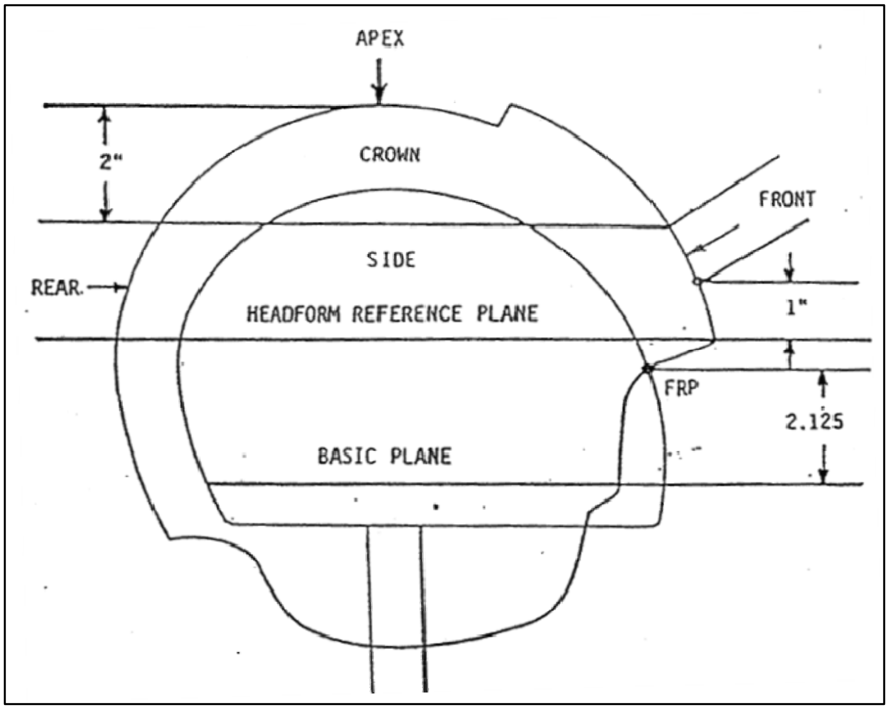


Figure 9. Helmet impact zones relative to test headform reference planes. Figure reproduced from the HGU-56/P AIHS production specification FNS/PD 96-18 (DOD, 1996).

Figure 10. MRU position relative to helmet impact regions. Although offset left of helmet center-line, the MRU boundaries remain with the crown impact region.

The eight helmets were divided into two groups of four helmets. One group included all small and all extra-large helmets; the second group contained all medium and large helmets. The group consisting of the small and extra-large helmets was tested at ambient temperature (70 ± 5 °F), while the second group was pre-conditioned at 122 ± 5 °F for at least 4 hours prior to testing (DOT, 1992).

Five impact sites were identified on each MRU (figure 11). Each helmet was subjected to single impacts at three sites on its respective MRU; one helmet in each size was impacted on MRU impact sites 1, 3, and 5, while the second helmet in each size was impacted on sites 2, 3, and 4. Given that the MRU boundaries remained within the crown region of each size helmet, all impacts to the small, medium, and large HGU-56/Ps configured with MRUs were conducted using test methods and pass-fail criterion specified in FNS PD 96-18 (DOD, 1996) for crown impacts to the HGU-56/P AIHS (table 2). These MRU impacts were conducted at 16.0 feet per second (fps).

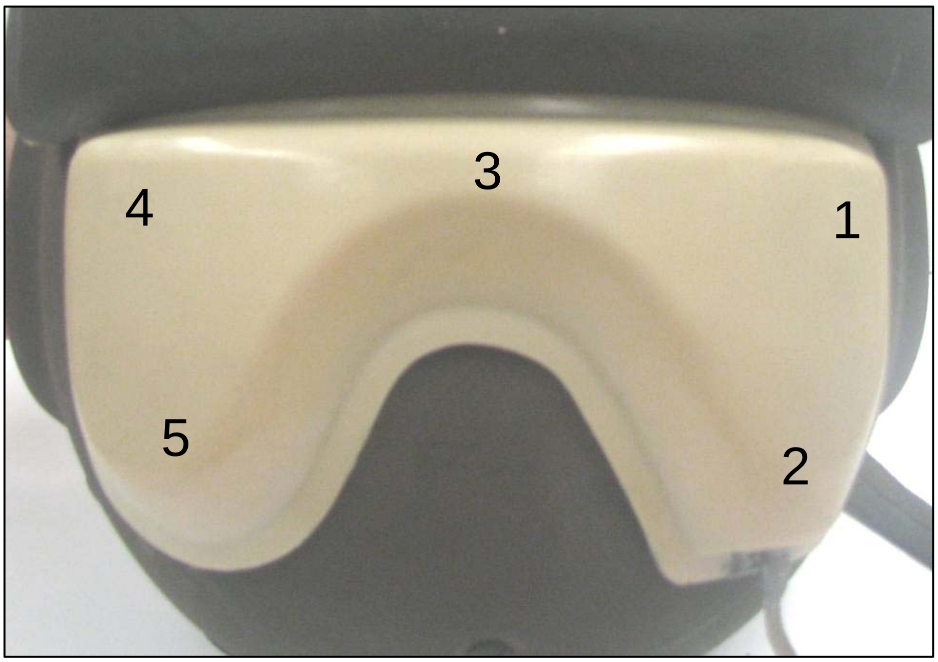


Figure 11. MRU impact sites.

Table 2.
Helmet impact velocity and headform peak acceleration requirements.

Impact site	Target impact velocity range (fps)*	Maximum peak headform acceleration (G)
Crown and left and right eardome	15.20 – 16.00	150
Front, rear, and left and right headband	18.70 – 19.69	175

* The impact velocity range is calculated based on the tolerance specified in ANSI Z90.1-1971 (1971), which is ±0% to -5% of the target velocity

Although the boundaries of the MRU were within the crown impact region, the outer edges of the MRU were near the transition between the crown and headband impact regions. A limited number of impacts were conducted at impact velocities corresponding to headband impacts. Impacts to MRUs installed on extra-large HGU-56/P helmets were conducted using test methods and pass-fail criteria specified in FNS PD 96-18 for headband and crown impacts (table 2). Impacts to MRU sites 1, 2, 4, and 5 were conducted as headband impacts with a target impact velocity of 19.69 fps, while impacts to MRU site 3 were performed at 16.0 fps.

For informational purposes and after all MRU impacts were complete, the small, medium, and large helmets were subjected to additional impacts. All three helmet sizes were impacted in the rear; small helmets were again tested at ambient laboratory temperature, while medium and large helmets were conditioned at 122 ± 5 °F (referred to as "hot") for at least four hours prior to testing. Eardome impacts were conducted on medium and large helmets at ambient laboratory conditions. These eardome and rear impacts were conducted in accordance with methods specified in FNS PD 96-18 (DOD, 1996). These impacts were performed for information purposes and were not intended to be used in assessing the effect of MRU installation on the blunt impact protection of the HGU-56/P AIHS.

All tests of environmentally conditioned helmets were conducted within 5 minutes of removing the helmets from the environmental chambers. If testing could not be completed within this time, the helmets were returned for a minimum of 15 minutes before resuming testing (DOD, 1996).

For each impact test, the test helmet was mounted to the headform. The helmet chin and nape straps were adjusted to achieve a snug fit; helmets were not allowed to fit loosely or droop from the headform. The combined helmet/headform assembly was raised to the drop height necessary to achieve the desired impact velocity and released. The helmet/headform assembly impacted a flat steel anvil at the base of the drop tower.

Helmet impact velocity, headform impact acceleration, and impact force were recorded during each test. The impact force was recorded for informational purposes only. After each test, each helmet was thoroughly inspected for loose components and distorted hardware. Also, test headform orientation was checked and adjusted if necessary.

Mass properties

The HGU-56/P helmets were fitted onto the test headform (figure 7). During CM measuring, the helmeted headform was positioned orthogonally in three orientations: XY, XZ, and YZ. A minimum of three measurements were made in each headform orientation with the helmet being removed and replaced between measurements. The multiple helmet removals and repositioning are conducted in an attempt to replicate minute, natural variations in the aviator helmet position that occur between repeated helmet donning and doffing cycles. The results for each axis were averaged to obtain the overall result.

Four configurations of the HGU-56/P flight helmet were measured and their mass properties recorded. These configurations included:

- one medium HGU-56/P with MRU and DVA (visors stowed),
- one medium HGU-56/P with MRU and SVA (visor stowed),
- one large HGU-56/P with MRU and DVA (visors stowed), and
- one large HGU-56/P with MRU and SVA (visor stowed).

Data analysis

Blunt impact protection

The headform accelerations were filtered at CFC 1000 according to SAE J211 (Society of Automotive Engineers, 1995) and the peak acceleration values were recorded for each helmet impact. Peak headform accelerations were compared to the 150-G pass-fail criterion for HGU-56/P crown and earcup impacts and the 175-G for rear impacts as specified in the HGU-56/P purchase specification (DOD, 1996). Any peak headform accelerations in excess of these thresholds would indicate that the modified HGU-56/P flight helmets offer less blunt impact protection than the standard HGU-56/P.

Mass properties

The Swedish Royal Institute of Technology (KTH) developed a validated, biofidelic finite element model of the human neck (Haldin et al., 2005). The KTH neck model predicts forces and moments acting on vertebral bodies, neck ligament strain, and stresses in the vertebrae and the intervertebral discs. As it is a mathematical model, additional head-supported mass can be added to the model at specific CM locations. This allows parametric studies of the effect of HSM and CM position on neck loads, ligament strain, etc.

The USAARL contracted with the KTH to conduct a series of simulations using this model. The purpose was to evaluate the influence of HSM and CM placement on the risk of acute neck injury during severe, but survivable dynamic impacts. The following parameters were included in the simulation runs (Haldin et al., 2005).

- Head-supported masses of 1, 2, and 3 kilograms (kg)
- Longitudinal CM positions of -2, 0, 2, 4, and 6 centimeters (cm) (relative to the head CM)
- Vertical CM positions of -2, 0, 2, 4, and 6 cm (relative to the head CM)
- Three impact acceleration levels of 5, 13.5, and 22 Gs
- Seven impact conditions of pure +Gx (forward), pure –Gx (rearward); pure +Gz (vertical), pure lateral (+Gy), combined longitudinal-vertical (Gxz), combined lateral-longitudinal (Gxy), and combined lateral-vertical (Gyz)

Forces and moments acting on the base of the neck (the junction of the seventh cervical and first thoracic [C7/T1] vertebrae) were computed for each combination of mass, longitudinal CM position, vertical CM position, impact condition, and impact acceleration. In turn, these data were used to calculate a corresponding Beam Criterion value (Bass et al, 2006). Bass et al. also showed that the risk of incurring an Abbreviated Injury Scale (AIS) 2 lower neck injury increases logarithmically as Beam Criterion values increases (Equation). Lower neck injuries classified as AIS 2 include:

- intervertebral disc herniation without nerve root damage,
- dislocation of one vertebra relative to another without vertebral body fracture or spinal cord contusion or laceration,
- vertebral fracture without spinal cord contusion or laceration or without dislocation (including burst fractures resulting in less than 20 % loss of vertebral height),
- laceration of the interspinous ligament,
- contusions to or a single laceration of or a single avulsion of the nerve root, and
- acute strain not resulting in fracture or dislocation.

$$Risk(BC) = \frac{1}{1 + \exp\left[\dfrac{1 - BC}{0.19}\right]} \qquad \text{(Equation)}$$

The mass, longitudinal CM positions, and vertical CM positions used in the simulations by Bass et al. (2006) did not match those measured during this evaluation of the HGU-56/P flight helmet. Therefore, for each combination of impact condition and impact acceleration, the Beam Criterion values resulting from the simulations were input into a multiple linear regression model. The resulting equations predicted Beam Criterion values as a function of HSM, longitudinal CM position, and lateral CM position. The mass properties of the various HGU-56/P helmets in the equipment configurations mentioned above were input into these regression equations to determine each helmet configuration's Beam Criterion value. In turn, these Beam Criterion values were input into the Equation to compute a corresponding risk of AIS 2 injury.

Additionally, USAARL conducted several in-house studies investigating the effects of HSM and longitudinal CM position on Soldier fatigue and performance. These studies show that HSM and longitudinal CM position had statistically significant effects on Soldier performance in visual tracking tasks and perceptions of helmet comfort and flight difficulty (Alem & Meyer, 1995; Alem & Fraser, 2006; Fraser, Alem, & Chancey, 2006). Comparisons between the HSM and CM positions tested during these studies and those measured during the present evaluation can be made to provide qualitative insight into possible performance decrements.

Results and discussion

Blunt impact protection

Peak headform accelerations were recorded during all MRU impacts. These accelerations were grouped by MRU impact site, helmet size, and visor type (figure 12). For small, medium, and large helmets configured with MRUs, impacts to all five MRU sites resulted in peak headform accelerations below the 150-G pass-fail criterion for crown impacts. This result was independent of helmet temperature at impact (ambient or 122 °F) and visor type (DVA or SVA). Additionally, impacts to MRU site 3 on extra-large HGU-56/P helmets also resulted in peak headform accelerations below the 150-G threshold. Impacts to MRU sites 1, 2, 4, and 5 on extra-large helmets, which were conducted at 19.69 fps, resulted in measured headform accelerations below the 175-G pass-fail criterion for headband impacts. Peak headform accelerations measured during MRU impacts are tabulated in appendix A, table A1.

Small, medium, and large HGU-56/P AIHSs equipped with MRUs were subjected to subsequent impacts to the rear headband and eardome areas of the helmets. Peak headform accelerations resulting from these impacts were grouped by helmet impact site and helmet size (figure 13). Right and left eardome impacts resulted in peak headform accelerations below the 150-G pass-fail criterion for eardome impacts (DOD, 1996). Three of six rear impacts resulted in headform accelerations in excess of 175 Gs, the pass-fail threshold for headband impacts (DOD, 1996). Figure 13 shows that helmet environmental conditioning did not have an effect; impacts to helmets conditioned at ambient laboratory temperature (small) and 122 °F (large) resulted in headform accelerations in excess of 175 Gs. Peak headform accelerations measured during rear headband and eardome impacts are tabulated in appendix A, table A2.

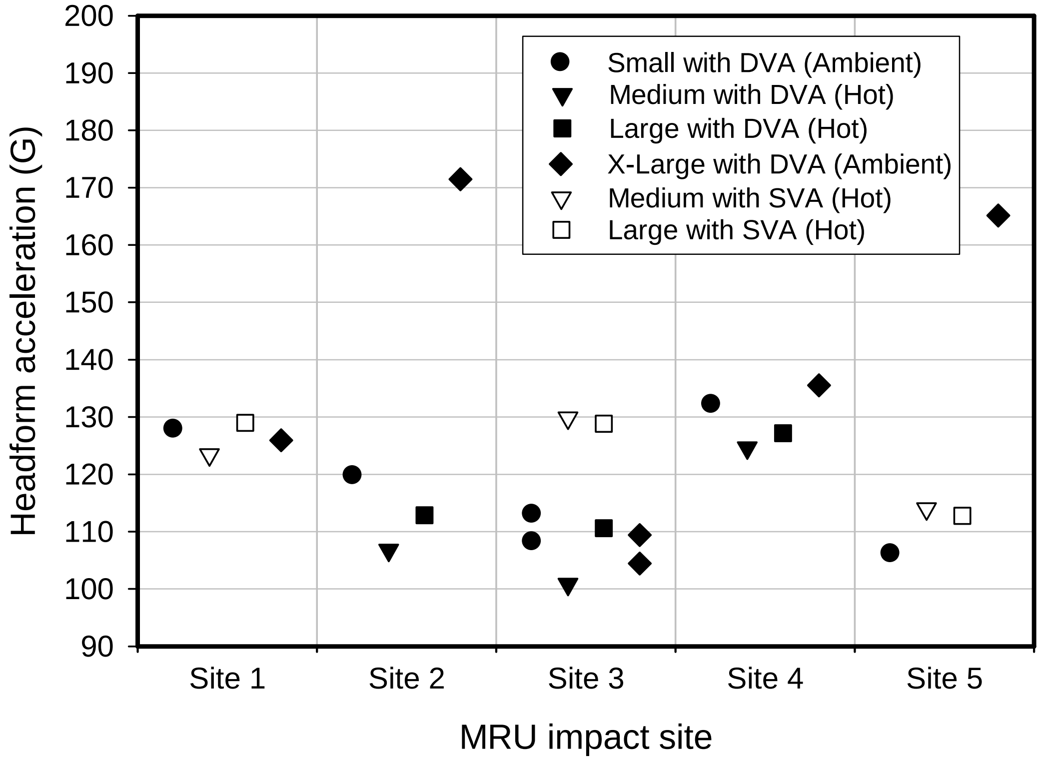


Figure 12. Peak headform accelerations recorded during MRU impacts. Filled and empty symbols represent impacts to helmets equipped with DVAs and SVAs, respectively. Impacts to small and extra-large helmets were conducted with helmets at ambient laboratory temperature (70 ± 5 °F). Impacts to medium and large HGU-56/Ps were conducted after hot environmental conditioning (122 ± 5 °F).

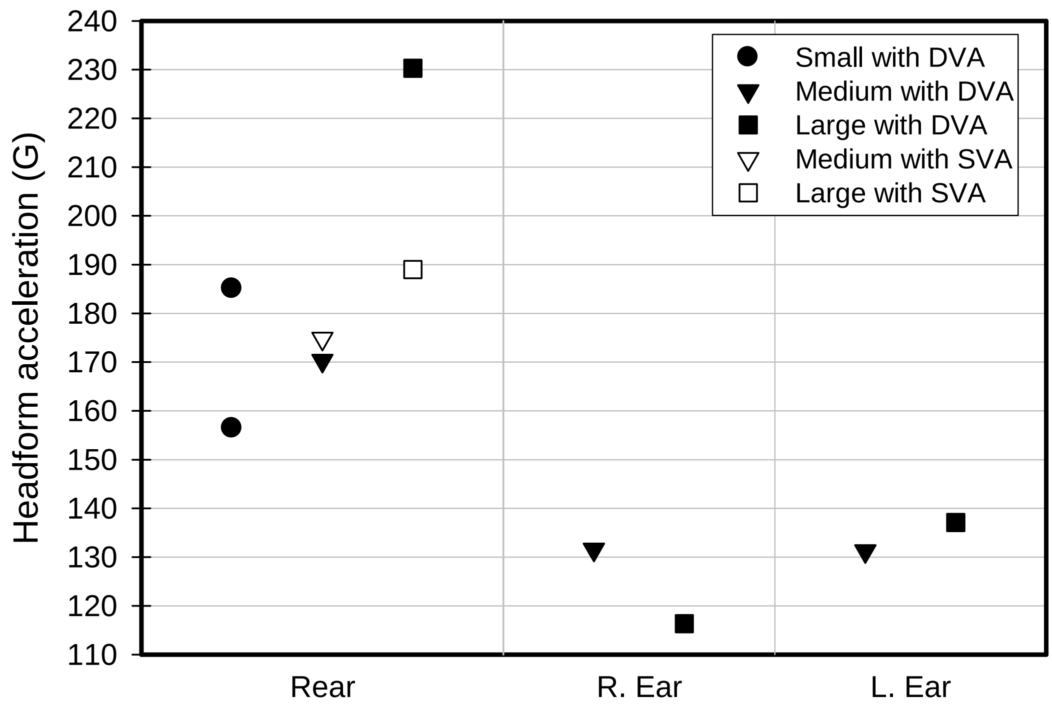


Figure 13. Peak headform accelerations measured during impacts to the rear, right and left eardomes of HGU-56/P helmets configured with MRUs. Rear impacts to medium and large HGU-56/Ps were conducted after environmental conditioning at 122 ± 5 °F. All other rear and eardome impacts were conducted with HGU-56/P helmets at ambient laboratory temperature. Filled and empty symbols represent impacts to HGU-56/P helmets equipped with DVAs and SVAs, respectively.

Historically, impacts to the rear headband of the HGU-56/P helmets have sporadically resulted in peak headform accelerations in excess of the 175-G threshold. Lot acceptance tests, which are conducted before the Government accepts delivery of batch of newly-constructed helmets to ensure the helmets meet design requirements, have produced peak headform accelerations of up to 192 Gs during rear impacts. The results of these lot acceptance tests have historically been waived by the Government on a case-by-case basis and the batches of helmet accepted.

The cause of the high rear headband accelerations measured during this test series is not readily apparent. One possible cause is that damage from previous impacts influenced the results of the rear headband impacts. Rear headband impacts were conducted after all MRU impacts were completed. MRU impact sites 2 and 5 were located near the rear headband impact area. Each small, medium, and large helmet was impacted at one of these two MRU impact sites. The

possibility, therefore, exists that impacts to MRU site 2 or 5 may have caused sufficient damage to the helmet's energy absorbing liner (EAL) to influence the results of the rear headband impacts. Prior damage to the EAL (in the form of compression of the expanded polystyrene) in the vicinity of the rear headband impact site could adversely affect the helmet's ability to absorb impact energy and result in elevated peak headform accelerations. HGU-56/P helmets were designed to limit headform accelerations to less than 175 Gs for a single impact; the performance of the helmet in multiple-impact situations has not been explored.

To investigate this hypothesis, one large HGU-56/P equipped with an MRU was conditioned at ambient laboratory temperature (70 ± 5 °F) and then impacted in the rear headband region. The resulting peak headform acceleration was 153.56 Gs. This helmet had not been subjected to any previous crown or headband impacts. Thus, the polystyrene EAL was free of any previous damage that could have influenced the performance of the helmet in a rear headband impact. This single data point supports the hypothesis that prior damage to the EAL may have contributed to the three peak headform accelerations that exceeded the pass-fail threshold of 175 Gs for rear headband impacts.

Installation of the MRU on the crown of the HGU-56/P did not appear to degrade the impact protection in the crown or eardomes of the helmet. Peak headform accelerations (figure 12) remained below the pass-fail criteria of 150 Gs and 175 Gs when MRUs were directly impacted at 16.0 fps and 19.69 fps, respectively (DOD, 1996). Additionally, headform accelerations measured during eardome impacts remained below the 150-G pass-fail threshold for eardome impacts (DOD, 1996).

Three of six rear headband impacts resulted in headform accelerations above 175 Gs; these accelerations were possibly influenced by prior impacts to the helmets. Even so, the HGU-56/P helmet limited peak headform acceleration to between 185 and 230 Gs (appendix A, table A2), indicating that the HGU-56/P equipped with the MRU provides improved impact protection when compared to the IHADSS. The IHADSS was designed to limit peak headform accelerations to 300 Gs (McEntire, 1998) at the crown and all headband impact sites.

Mass properties

The mass, average CM locations measured along the longitudinal (anterior-posterior), lateral (left-right), and vertical axes, and weight moments for the four configurations of HGU-56/P flight helmets described above are presented in Table 3. All CM locations were measured relative to the tragion notch; the weight moments represent the pitching moment about the lateral axis (the axis running from left ear to right ear through the tragion notch). For comparison purposes, historical data on the mass and CM location of standard, unmodified medium and large HGU-56/P helmets is included in table 3.

Table 3.
Mass and CM positions.

Equipment configuration	Mass (kg)	X-axis (mm)	Y-axis (mm)	Z-axis (mm)	Weight moment (N-cm)
Medium standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	1.358	9.005	5.602	45.748	12.00
Medium HGU-56/P with MRU & DVA (visors stowed)	1.582	-3.610	2.915	55.515	-5.60
Medium HGU-56/P with MRU & SVA (visor stowed)	1.638	7.974	3.115	61.442	12.81
Large standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	1.365	6.634	6.983	42.112	8.89
Large HGU-56/P with MRU & DVA (visors stowed)	1.612	4.143	3.087	52.518	6.55
Large HGU-56/P with MRU & SVA (visor stowed)	1.664	10.643	4.213	58.988	17.37

As expected, the mass of the medium and large HGU-56/P flight helmets equipped with the standard DVA increased as additional equipment (i.e., the MRU) was added to the helmet (table 3). Addition of the MRU caused the CM of the medium and large HGU-56/P helmets to shift rearward (represented by a reduction in X-axis CM position as compared to the unmodified helmet) and upward (indicated by an increase in Z-axis CM position). Installation of the MRU also resulted in the helmet becoming more balanced about the mid-sagittal plane (indicated by the Y-axis CM position tending toward a value of 0), as the mass of the MRU offsets the mass of the microphone boom mounted to the left eardome. Replacing the DVA with the SVA increased the mass of MRU-equipped medium and large HGU-56/P helmets and shifted the CM position of these helmets forward and upward.

Acute injury

Mass and CM position data for each large HGU-56/P flight helmet configuration (table 3) were used to compute Beam Criterion values and AIS 2 lower neck injury risks for the 5-, 13.5-, and 22-G impact accelerations and the vertical (+Gz), longitudinal (-Gx), and combined longitudinal-vertical (Gxz) impact conditions. The combined Gxz impact condition was the worst case impact condition, as simulations involving this impact condition resulted in the highest Beam Criterion values and injury risks. As the worst case condition, all injury risk assessments were based on the combined Gxz impact condition (table 4). Beam Criterion values and associated injury risks for all helmet configurations and impact conditions are tabulated in appendix B, table B1.

Table 4 shows a consistent trend across the six HGU-56/P configurations. Beam Criterion values and injury risk increased with increased impact acceleration levels, for a given equipment configuration (table 4). This trend was expected considering greater impact accelerations result in higher inertial loading of the neck. While only results for the combined Gxz impact condition

are presented, this trend held true for all combinations of impact conditions and impact accelerations (table B1).

Table 4.
Predicted Beam Criterion values and associated injury risks for medium and large HGU-56/P helmets equipped with MRUs and either DVAs or SVAs in the combined longitudinal-vertical impact condition.

Equipment configuration	Beam Criterion values			AIS 2 injury risk (percent)		
	5-G	13.5-G	22-G	5-G	13.5-G	22-G
Medium standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.24	0.73	1.15	1.77	19.63	68.94
Medium HGU-56/P with MRU & DVA (visors stowed)	0.24	0.73	1.11	1.81	19.68	64.22
Medium HGU-56/P with MRU & SVA (visor stowed)	0.25	0.75	1.14	1.89	20.87	67.56
Large standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.23	0.73	1.15	1.75	19.41	69.19
Large HGU-56/P with MRU & DVA (visors stowed)	0.24	0.74	1.15	1.84	20.29	68.38
Large HGU-56/P with MRU & SVA (visor stowed)	0.25	0.75	1.16	1.91	21.11	69.53

The addition of the MRU had little impact on the risk of acute neck injury for either size helmet. For the worst-case, Gxz impact condition, the Beam Criterion values and their corresponding injury risks remained almost constant between the standard HGU-56/P helmets with DVAs and HGU-56/Ps helmets with MRUs and DVAs with the largest increase in injury risk being slightly less than 5 %. Replacing the DVA with SVAs on MRU-equipped HGU-56/P helmets resulted in little increase in injury risk; the largest increase in injury risk was found to be less than 3 %.

The AIS classifications are based on the likelihood of an injury resulting in death. AIS classifications range from 1 to 6, with an AIS 6 injury being unsurvivable. AIS 2 injuries, like those the Beam Criterion is intended to predict, are considered moderate and do not involve the spinal cord. Therefore, in normal, healthy individuals, such as U.S. Army aviation crewmembers, AIS 2 injuries are non-fatal and not life-threatening. Also, injuries of this nature are not disabling and would be unlikely to hinder a crewmember's ability to egress an aircraft.

Performance implications

The masses and longitudinal CM positions of the medium and large HGU-56/P helmet configurations are presented in figure 14. The solid black curve shown in each figure represents a constant 78 Newton-centimeter (N-cm) weight moment about the tragion notch. The large black squares represent combinations of HSM and longitudinal CM position tested by Alem and Frasier (2006) during studies of aviator flight performance and vigilance during 1.5-hour sorties in the USAARL NUH-60 research flight simulator. The numbers in bold near each black square represent helmet configuration's corresponding weight moment relative to the tragion notch.

Alem and Meyer (1995) subjected volunteer subjects to 4, 4-hour simulated helicopter rides with varying combinations of HSM and longitudinal CM position. During each 4-hour session, subjects were asked to track moving targets. The amount of time necessary to acquire the targets and extinguish them (by holding a laser on the target for about 1 second) was recorded. Analysis showed that subjects' abilities to consistently track a moving target degraded (the amount of time needed to acquire and extinguish the target increased) at weight moments above 78 N-cm.

Alem and Fraser (2006) found a similar effect during volunteer studies in the NUH-60 flight simulator. Target acquisition time was found to increase as weight moment increased. While Alem and Fraser (2006) did not identify a critical weight moment value, they did show that HSM had a significant effect on target acquisition time, with greater HSM corresponding to increased acquisition time.

Weight moments for the six HGU-56/P helmet configurations fell below the 78 N-cm curve and clustered near 15 N-cm (figure 14). Based on the two studies described above, it can be inferred that aviators wearing HGU-56/P helmets equipped with MRU and DVA or SVA will take about the same time to acquire and identify targets (e.g., other aircraft, ground-based threats) as those flying with an unmodified HGU-56/P helmet. Additionally, aviators in flight would likely experience the similar levels of fatigue and discomfort while wearing MRU-equipped HGU-56/P helmets as when flying the standard HGU-56/P flight helmet (Alem and Frasier, 2006).

Study limitations

The linear regression models used to calculate Beam Criterion values are based on the results of finite element simulations whose input parameters were described previously. In this study, Beam Criterion values were subsequently used to predict AIS 2 lower neck injury risk using the Equation. The input parameters did not include all conceivable impact orientations and acceleration levels. These results should not be extrapolated to determine injury risks for impact orientations and acceleration levels other than those described previously.

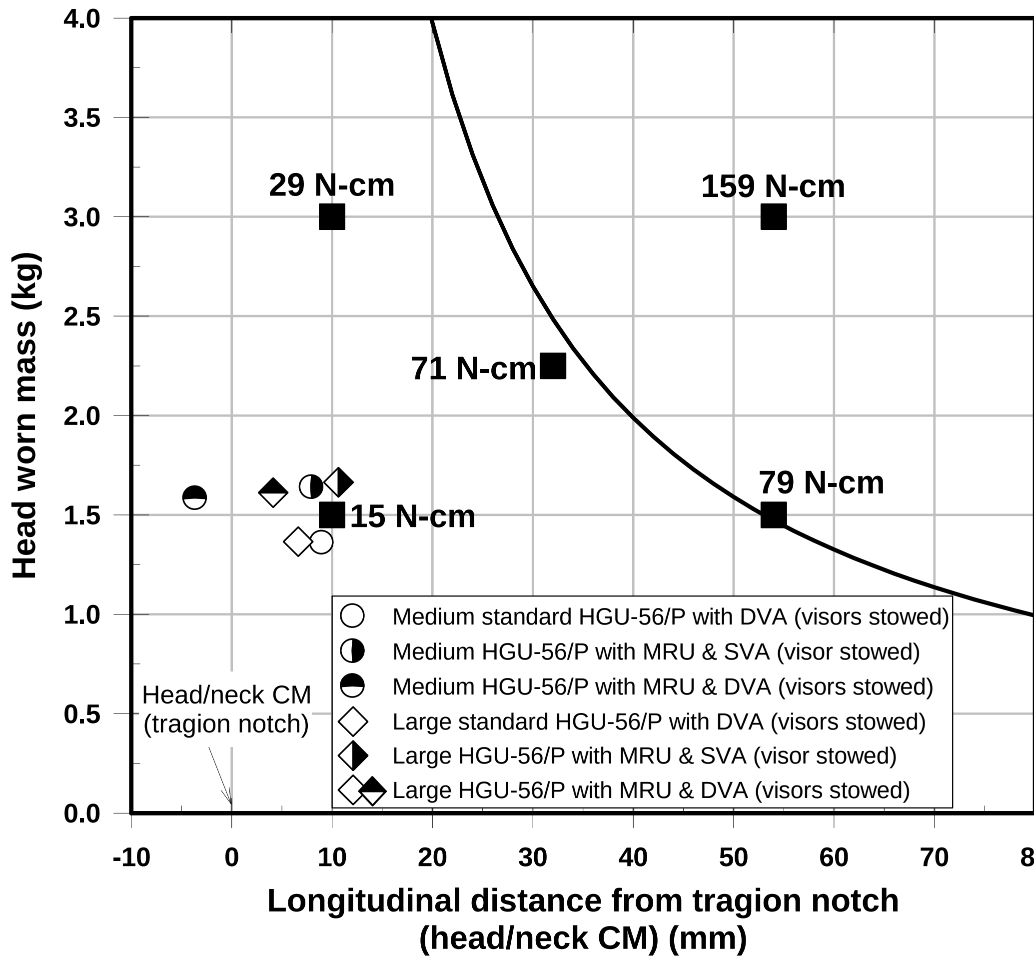


Figure 14. Mass and longitudinal CM position of large HGU-56/P helmets in various equipment configurations. The solid black line represents a constant weight moment of 78 N-cm about the tragion notch. The five large, solid black squares represent combinations of HSM and longitudinal CM position tested by Alem and Frasier (2006) during studies of pilot performance.

Conclusions

HGU-56/P AIHSs equipped with the MRU should provide adequate impact protection in survivable rotary-wing mishaps. When modified with the MRU, the HGU-56/P flight helmet limits headform accelerations to less than the 150-G criterion during crown impacts whether tested at ambient or hot temperatures. During direct impacts to the MRU at target impact velocities consistent with headband impacts (19.69 fps), MRU-equipped HGU-56/P helmets limited accelerations to less than 175 Gs, the pass-fail criterion for headband impacts. Further,

addition of the MRU to the HGU-56/P AIHS did not adversely affect the lateral impact protection provided by the helmet, as shown by the results of eardome impacts.

Impacts to the rear of three of the six MRU-equipped HGU-56/P AIHSs resulted in peak headform accelerations in excess of the 175-G pass-fail criterion. However, additional testing suggests that these results were probably influenced by prior damage to the helmet's EAL, and therefore, are not indicative of the performance of an undamaged MRU-equipped HGU-56/P AIHS. Based on the results of this study, no definitive statement can be made as to the influence of the MRU installation on the blunt impact protection provided by the HGU-56/P when impacted in the rear. However, MRU-equipped HGU-56/Ps provide improved impact protection in the rear headband region of the helmet when compared to the IHADSS.

Installing an MRU on the HGU-56/P flight helmet increases helmet weight and alters the position of the helmet CM relative to the tragion notch when compared to an unmodified helmet. However, the additional mass and change in CM did not appreciably increase the risk of sustaining acute lower neck injury at the acceleration levels and impact orientations described herein. In addition, installation of the MRU should not adversely affect the wearer's ability to identify and track targets.

<u>References</u>

Adams, M.S., Mando, V., Hart, J.G., Jones, J., McEntire, B.J., Brozoski, F.T., and Licina, J.R. In press. <u>HGU-56/P U.S. Army Flight Helmet Performance 1996 – 2004</u>. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. TBA.

Alem, N.M. and Fraser, S., presented by Chancey, V.C. 2006. "Effects of head supported mass on pilot performance during UH-60 flight simulations." Presentation to the 77th Annual Scientific Meeting of the Aerospace Medical Association, Orlando, FL, May 2006.

Alem, N.M. and Meyer, M.D. 1995. <u>Effects of head supported devices on pilot performance during simulated helicopter rides.</u> Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 95-37.

Bass, C.R., Donnellan, L., Salzar, R.S., Lucas, S.R., Folk, B., Davis, M., Rafaels, K.A., Planchak, C., Meyerhoff, K., Ziemba, A., Alem, N. 2006. <u>A new neck injury criterion in combined vertical/frontal crashes with head supported mass</u>. Proceedings of the 2008 International IRCOBI Conference on the Biomechanics of Impact, Madrid, Spain, September 20 – 22, 2006.

Deavers, M.B. and McEntire, B.J. 1996. <u>An automated method for determining mass properties</u>. US Army Aeromedical Research Laboratory. Fort Rucker, AL. USAARL report: 93-4.

Department of Defense. 1996. <u>Purchase description: Aircrew integrated helmet system, HGU-56/P (AIHS)</u>. FNS/PD 96-18. November 1, 1996.

Fraser, S., Alem, N.M., and Chancey, V.C. 2006. "Helicopter flight performance with head-supported mass." Proceeding of the 62nd Annual Meeting of the American Helicopter Society Annual Forum, Phoenix, AZ, May 9 – 11, 2006.

Haldin, P., Brolin, K., Hedenstierna, S., Aare, M., von Holst, H. 2005. <u>Finite element analysis of the effects of head supported mass on neck responses - Complete Phase Two Report</u>. Stockholm, Sweden: Royal Institute of Technology, School of Technology and Health, Division of Neuronic Engineering. Contractor report to U.S. Army. Contract number N62558-03-C-0013.

Hundley, T.A. and Haley, J.L. 1984. <u>Energy-absorbing earcup engineering feasibility evaluation</u>. U.S. Army Aeromedical Research Laboratory. Fort Rucker, AL. USAARL Report No. 84-6.

McEntire, B.J. (1998a). U.S. Army aircrew helmets: Head injury mitigation technology (Reprint). Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report: 98-12.

Shanahan, D.F. 1983. Basilar skull fracture in U.S. Army aircraft accidents. Aviation Space and Environmental Medicine. 54(7):628-631. July 1983.

Slobodnik, B.A. 1980. SPH-4 helmet damage and head injury correlation. Fort Rucker, AL: U.S. Army Aeromedical Research Laboratory. USAARL Report No. 80-7.

Society of Automotive Engineers. 1995. Recommended Practice J211-1. Instrumentation for impact test – Part 1 – Electronic instrumentation. Warrendale, PA.

Travis, L.W., Stalnaker, R.L., and Melving, J.W. 1977. Impact trauma of the human temporal bone. The Journal of Trauma. 17(10):761-766.

U.S. Department of Transportation. 1992. Federal Motor Vehicles Safety Standard 218. Sec. 571.218, Standard No. 218, FMVSS 218 – 49 CFR 571.218.

Appendix A.
Tabulated peak headform acceleration data from all blunt impacts.

Table A1.
Peak headform accelerations for all MRU impacts.

Helmet size	Helmet number	Visor type	Environmental conditioning	MRU impact site	Impact velocity (fps)	Peak headform acceleration (G)*
Small	1	DVA	Ambient	Site 2	15.86	119.79
				Site 3	15.90	113.04
				Site 4	15.86	132.23
	2	DVA	Ambient	Site 1	15.86	127.90
				Site 3	15.92	108.25
				Site 5	16.01	106.18
Medium	1	DVA	Hot	Site 2	15.90	106.76
				Site 3	15.88	100.82
				Site 4	15.90	124.61
	2	SVA	Hot	Site 1	15.84	123.44
				Site 3	15.84	129.84
				Site 5	15.84	114.00
Large	1	DVA	Hot	Site 2	15.82	112.85
				Site 3	15.78	110.61
				Site 4	15.86	127.16
	2	SVA	Hot	Site 1	15.80	129.00
				Site 3	15.86	128.83
				Site 5	15.78	112.77
Extra-large	1	DVA	Ambient	Site 2	19.62	171.47
				Site 3	15.86	109.40
				Site 4	19.47	135.52
	2	DVA	Ambient	Site 1	19.65	125.93
				Site 3	15.84	104.43
				Site 5	19.59	165.14

* Peak headform accelerations were filtered at 1650 Hz (CFC 1000) in accordance with SAE J211 (Society of Automotive Engineers, 1995).

Table A2.
Peak headform accelerations for rear and eardome impacts.

Helmet size	Helmet number	Visor type	Environmental conditioning	Helmet impact site	Impact velocity (fps)	Peak headform acceleration (G)*
Small	1	DVA	Ambient	Rear	19.62	185.08
	2	DVA	Ambient	Rear	19.56	156.43
Medium	1	DVA	Hot	Rear	19.72	170.32
			Ambient	Right eardome	19.62	131.55
			Ambient	Left eardome	19.62	131.24
	2	SVA	Hot	Rear	19.53	174.83
Large	1	DVA	Hot	Rear	19.65	230.29
			Ambient	Right eardome	19.62	116.32
			Ambient	Left eardome	19.62	137.09
	2	SVA	Hot	Rear	19.59	189.00

* Peak headform accelerations were filtered at 1650 Hz (CFC 1000) in accordance with SAE J211 (Society of Automotive Engineers, 1995).

Appendix B.
Beam Criterion values and associated injury risks.

Table B1.
Predicted Beam Criterion values and associated injury risks for medium and large HGU-56/P helmets equipped with MRUs and either DVAs or SVAs in combined longitudinal-vertical, vertical, and longitudinal impact conditions.

Equipment configuration	Beam Criterion values			AIS 2 injury risk (percent)		
	5-G	13.5-G	22-G	5-G	13.5-G	22-G
Oblique (Gxy)						
Medium standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.24	0.73	1.15	1.77	19.63	68.94
Medium HGU-56/P with MRU & SVA (visor stowed)	0.25	0.75	1.14	1.89	20.87	67.56
Medium HGU-56/P with MRU & DVA (visors stowed)	0.24	0.73	1.11	1.81	19.68	64.22
Large standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.23	0.73	1.15	1.75	19.41	69.19
Large HGU-56/P with MRU & SVA (visor stowed)	0.25	0.75	1.16	1.91	21.11	69.53
Large HGU-56/P with MRU & DVA (visors stowed)	0.24	0.74	1.15	1.84	20.29	68.38
Vertical (Gz)						
Medium standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.14	0.40	0.71	0.93	2.51	10.56
Medium HGU-56/P with MRU & SVA (visor stowed)	0.15	0.43	0.74	0.94	2.54	10.75
Medium HGU-56/P with MRU & DVA (visors stowed)	0.15	0.43	0.74	0.94	2.54	10.76
Large standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.14	0.40	0.71	0.93	2.51	10.57
Large HGU-56/P with MRU & SVA (visor stowed)	0.15	0.43	0.74	0.94	2.54	10.74
Large HGU-56/P with MRU & DVA (visors stowed)	0.15	0.42	0.74	0.94	2.54	10.73
Longitudinal (Gx)						
Medium standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.31	0.77	1.04	1.77	14.21	40.35
Medium HGU-56/P with MRU & SVA (visor stowed)	0.33	0.80	1.06	1.77	14.18	40.35
Medium HGU-56/P with MRU & DVA (visors stowed)	0.33	0.80	1.05	1.78	14.76	40.22
Large standard HGU-56/P with DVA (visors stowed) (helmet only - no additional equipment)	0.31	0.77	1.04	1.78	14.30	40.32
Large HGU-56/P with MRU & SVA (visor stowed)	0.33	0.80	1.06	1.77	14.04	40.38
Large HGU-56/P with MRU & DVA (visors stowed)	0.33	0.79	1.06	1.78	14.38	40.31

Appendix C.
List of manufacturers.

3M
3M Corporate Headquarters
3M Center
St. Paul, MN 55144-1000

Denton ATD, Inc.
2967 Waterview Drive
Rochester Hills, MI 48309

Elbit Systems of America
U.S. Corporate Headquarters
4700 Marine Creek Parkway
Fort Worth, TX 76179-6969
Endevco

Gentex Corporation
P.O. Box 315
Carbondale, PA 18407

Space Electronics, Inc.
81 Fuller Way
Berlin, CT 06037

DEPARTMENT OF THE ARMY

U.S. Army Aeromedical Research Laboratory

Fort Rucker, Alabama 36362-0577